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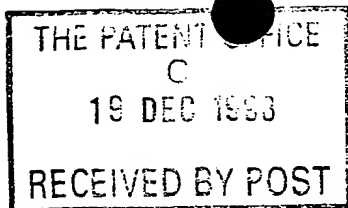
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210EC98 E413114-1 D02973
P01/7700 0.00 - 9827944.1

Request for grant of a patent

1	Your reference	
		P 20963 GB

2	Patent application number	
		'19 DEC 1998 **9827944.1**

3	Full name, address and postcode of the applicant	The Secretary of State for Defence **Defence Research Evaluation Agency Ively Road, Farnborough Hampshire GU14 6TD**
	Patents ADP number	S45 10013
	State of incorporation	**United Kingdom**

4	Title of the invention	
		Displays Based on Multiple Digital Bit Planes

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	Patents ADP number	1457/002

6	Priority applications	Country	Priority App No	Date of Filing

7	Parent application (eg Divisional)	Earlier Application No	Date of Filing

8	Statement of Inventorship Needed?	Yes

9 Number of sheets for any of the following
(not counting copies of same document)

Continuation sheets of this form	0
Description	11
Claims	2
Abstract	0
Drawings	0

10 Number of other documents attached

Priority documents	
Translations of priority documents	
P7/77	
P9/77	1
P10/77	0
Other documents	**covering letter**

11 I/We request the grant of a patent on the basis of this application.

Signature _Harrison Goddard Foote_   18th December 1998

Harrison Goddard Foote

12 Name and daytime telephone number of
person to contact in the United Kingdom

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Displays Based on Multiple Digital Bit Planes

5   The present invention relates to methods of operating a display or spatial light modulator in which the instantaneous intensity distribution afforded by the display is binary in nature but the display is altered sufficiently quickly that a time averaged display appears to have multiple intensity levels.

10   Temporally varying binary modulation to achieve a multiple intensity effect is known, and where spatial light modulation is achieved by the use of an array of individually addressable cells or pixels, it can be effected by the use of bit planes. In such a scheme, an array of digitised values, of amplitudes corresponding to the grey scale values allocated to the pixels of the array, is decomposed into a plurality of bit

15   planes.

While it is possible to decompose a n-level grey scale image into a plurality of binary image planes of equal duration, with a corresponding plurality of bitplanes of equal duration, in the preferred form, the weighted bit plane technique, the durations of the

20   bit planes are weighted, each bitplane being representative of one level (exponent) of the digitisation. This reduces the number of bit planes required to synthesise an image, and reduces addressing requirements somewhat.

Commonly the digitisation is binary, so that each bit plane is an array of digital 1s

25   and 0s, and it is then only necessary to display each bit plane for a total period proportional to its binary weighting to provide a time averaged image equivalent to the digitised grey scale image.

Where possible, it is convenient to display each binary bit plane once for the total

30   duration necessary to contribute to the grey scale image, but it is also possible to display one or more of the bit planes a plurality of times, not necessarily sequentially,

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provided that the total time spent in displaying each bitplane, relative to the total time spent in displaying all the bitplanes, is proportional to its binary weighting.

Although in certain cases, it would be possible to use digital bases other than 2, this complicates matters insofar as each bit plane is not binary and thus is not so easily stored. Furthermore, each location of such a bit plane would then have more than one non-zero value, and the variation in non-zero values across the bit plane would need to be taken into account for the times to be spent in display. The discussion below will be limited to binary weighting.

The multiple bit plane technique may be used with any array type display device capable of providing a sequence of binary displays sufficiently quickly to give the appearance of a multi-intensity display, including those capable of modulating incident light and those which produce light. The term "array imaging device" used herein is intended to cover both of the latter types of device, and also similar devices which are used to provide time averaged grey scale imagewise light distributions not for display purposes.

Recently there has been developed a novel spatial light modulator in the form of a smectic liquid crystal layer disposed between an active semiconductor backplane and a common front electrode. It was developed in response to a requirement for a fast and, if possible, inexpensive, spatial light modulator comprising a relatively large number of pixels (320 x 240 up to 640 x 480) with potential application not only as a display device, but also for other forms of optical processing such as correlation and holographic switching. Depending on the manner in which it is driven, and the value of the applied voltage, the modulator may be driven at a line rate of at least 10MHz and a frame rate of up to 15 to 20kHz, requiring a data input of around 1 to 1.5 Gpixel per second. Typically, while the pixel address time is around 100 nanoseconds, the pixel will actually take around 1 to 5 microseconds to switch between optical states; and while overall frame writing time is of the order of 24 microseconds, the frame to frame writing period is around 80 microseconds.

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This spatial light modulator can be driven according to single pass schemes, in which the front electrode is placed at a potential of V/2 relative to the backplane pixels, which are switched to zero volts or V volts.

5   Alternatively it can be driven according to double pass schemes in which in one pass the front electrode is placed at zero volts and selected pixels are turned ON by switching pixel elements of the backplane array to V volts, and in the other pass the front electrode is placed at V volts and selected pixels are turned OFF by switching elements of the array to zero volts. For pixels which are not in the process of being

10   switched the elements of the backplane follow the voltage of the front electrode. To maintain the same potential difference therebetween, the voltage at all backplane pixel elements of the array is simultaneously switched as the voltage on the front electrode is changed between zero and V volts.

15   Our copending applications (ref: P20956GB; P 20957GB; P20958GB; P20959GB; P20960GB; P20961GB; and P20962GB; relate to other inventive aspects associated with this spatial light modulator, including the single and double pass schemes referred to in the preceding paragraph.

20   The aforesaid spatial light modulator is ideally suited to the use of the bitplane technique mentioned above. However, the present invention is not limited to liquid crystal modulators, but can be applied to any array imaging device as referred to above.

25   One problem which arises, particularly when operating liquid crystal display and modulators, is that of maintaining a dc balance at individual pixels. Initially, liquid crystal light modulators were in the form of a single cell comprising a layer of liquid crystal material sandwiched between opposed electrode bearing plates, at least one of the plates being transparent. Such cells were slow to operate and tended to have a

30   short life due to degradation of the liquid crystal material. Quite early on it was recognised that the application of an average finite dc voltage to the liquid crystal cell

was not beneficial, and at least in some cases produced degradation by electrolysis of the liquid crystal material itself, and schemes were evolved to render the average dc voltage to zero (dc balance).

5   It is now appreciated that other effects are also at work when a dc voltage is applied. When driving liquid crystal electro-optic devices for any length of time, a phenomenon known as image sticking may occur. Although the precise cause of this effect is unknown, there are theories that ions are trapped or a space charge is induced within the material in response to an overall dc field, and this results in a residual

10   field even when the external dc field is removed.

It is evidently desirable that the time averaged voltage (that is, the average over the time that the voltage is actually being applied from an external source to the liquid crystal) applied to a liquid crystal material is zero, whether to avoid degradation or to

15   avoid image sticking.

Grey Scales   Temporal digital modulation to achieve a grey scale effect is known, using **multiple bit planes** representative of a sequence of binary images. The effective duration of the binary images (length and/or number of repeats) is such that

20   temporal integration thereof, for example by a viewer, gives the grey scale image.

Although repetition of identical binary images may be involved in such a sequence, the production of effective grey scales is best effected by the use of **weighted bit planes** where possible. In such a scheme, the grey scale image is decomposed into

25   multiple binary images (bit planes) of differing duration such that temporal integration thereof, for example by a viewer, gives the grey scale image. The decomposition of the grey scale image and the corresponding durations of the bit planes, are typically on a binary basis, although other weightings could be used.

30   The different bit planes for a grey scale image can be stored as sequential binary strings in a computer, and will be read out one at a time in any desired order after

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which they can be discarded unless the image needs to be repeated. It is computationally easiest to read out the bit planes in the order in which they have been stored, since then the only address which needs to be stored is the starting address of the first stored bit planes, all bit planes then being read out one at a time simply by clocking out a predetermined number of data bits in sequence for each bit planes.

It might be possible immediately to replace bit planes that have been read by the bit planes for a succeeding image, particularly where the bit planes are being produced in real time. However, under other circumstances this could be difficult, and the set of bit planes for a successive image will then normally be stored elsewhere. In certain cases it would be possible to provide storage for just two bit planes one of which is written while the other is being read, and vice versa.

It would also be possible to control the reading and/or writing processes so as to convert the image standards as desired, for example from line sequential to interlaced.

As or after each bit plane is read from memory, it is then written, e.g. using the single pass scheme described above, and viewed over a period corresponding to its weighting so that the eye synthesises the intended grey scale image. The single pass scheme is preferred insofar as it merely over-writes the preceding bit frame without the need for a second pass, the associated front electrode switching and blanking pulses. The avoidance of lost time between successive valid images enables continuous illumination and the easier provision of bit frames of an accurately weighted duration.

In such a scheme, each pixel is subjected to a series of voltage pulses according to the point in the grey scale it represents (as in the number representing the grey scale level, and usually but not necessarily in that order). There are more points in the grey scale than there are applications of voltages, due to the weighting employed, which is advantageous since it reduces the time spent actually driving the array. Each applied voltage may be of the same or opposed polarity compared to the preceding voltage,

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and the same number of voltage pulses, equal to the number of bit planes (ignoring polarity), is applied to each pixel to synthesise the image.

For example, in a 64 level grey scale with binary weighting, there will be 6 bit planes with relative durations of $2^n t$ where n ranges from 0 to 5, and each pixel can be represented by a corresponding 6 digit binary number.

However, double pass schemes could alternatively be adapted for use in multiple or weighted bit plane schemes.

To achieve dc balance, it would be possible to produce each binary bit plane by any binary imaging method which itself produces dc balance - for example by starting from a blank image, writing, viewing and erasing the binary image by selective energisation (+V) and driven blanking (-V) of selected pixels only.

However, in most or all of such schemes, the actual duration of the binary image is not directly proportional to the time allocated thereto, for example because of intervening blanking steps, etc., leading to a degree of distortion in the binary nature of the bitplane periods, and hence the perceived grey scale values. While this could be compensated for if desired, it represents an additional complication.

The present provides multiple or weighted bit plane schemes in which dc balance is approached or achieved in ways other than by employing dc balanced binary images per se.

For any selected pixel, each grey scale level can be represented by a binary number, and there are certain binary numbers which possess equal numbers of 0 and 1 digits, for example 111000 and 010101. In these cases the average dc voltage over the 6 bit planes will be zero. Other binary numbers, such as 011000 and 010001 come close to this ideal, and others, in particular 111111 and 000000 are far removed therefrom.

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Thus to achieve dc balance in such a scheme, another possibility is (a) to use only those numbers which by themselves achieve dc balance, or (b) at least to alter the grey scale numbers to closely adjacent numbers which closely approach dc balance. This permits use of a single or double pass scheme (see above, and also our copending applications P20961GB and 20962GB), addressing all elements during each scan. Some of these schemes per se normally provide no inherent dc balance, and yet in this case dc balance or at least an approximation thereto can be obtained over the grey scale imaging time.

In the first instance (a), where the desired grey level differs, it is approximated by the nearest such number in value, for example 000110 becomes 000111, and 100010 becomes 100011. A drawback is that there can be significant distortion of the greyscale.

In the second instance (b), distortion of the greyscale can be reduced but at the expense of precise dc balance. For example, the number 001000 may become 001001, and 110111 may become 110110.

In either instance, unless further corrective steps are taken, extreme values of the grey scale will be omitted (e.g. replaced by an adjacent less extreme value), thus reducing or compressing the contrast range somewhat.

Accordingly, the invention provides a method of grey scale imaging using a weighted bit plane technique, in which an n-digit binary number represents the intended grey level of each pixel location in an array of binary pixels, wherein at least one said binary number has an unequal number of 1s and 0s, said method comprising the step of altering the number to a closely adjacent value such as to reduce the inequality of 1s and 0s.

In a refinement, time averaging of both dc and grey scale level is performed over more than one frame, by suitable choice of the binary numbers. In this manner, dc

balance can be closely approximated, or preferably attained, while the average grey scale level can be approximated or, preferably, maintained. For example, 110110 (27) could be replaced by 001110 (28) in a first frame and by 010110 (26) in second frame. The average grey scale level is 27 as desired, and both the binary numbers
5   actually used provide dc balance per se.

In a more complicated example, the grey scale level 15 (111100) could be used twice together with an additional frame for grey level 14 (011100) and another additional frame for grey level 16 (000010), the frames in any desired order. Over the four
10   frames the average grey level is 15, and there are equal numbers of binary 1s and 0s.

Accordingly, the invention also provides a method of writing and displaying a grey scale image using a weighted bit plane technique, in which an n-digit binary number represents the intended grey level of each pixel location in an array of binary pixels,
15   wherein at least one said binary number has an unequal number of 1s and 0s, in which a plurality of images approximating said grey scale image are written in succession, said method comprising the step of altering the number to closely adjacent values over said plurality of images such as to reduce the inequality of 1s and 0s. Preferably the inequality is eliminated. The grey scale as measured over the plurality of images
20   is at least approximated, but preferably maintained.

Again extremes of the grey scale are preferably omitted. If in either case, the full grey scale ranges are retained, dc balance can be periodically restored by other means, for example by applying corrective dc pulses as appropriate following a computer
25   simulation of the dc imbalance which has accumulated, as mentioned above. However, this is not normally preferred, since it potentially involves using a number of corrective dc pulses equal in number to the number of bit planes which have been used, to allow for the possibility that at least one pixel has remained at an extreme grey scale value throughput the imaging period.

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These ways of maintaining dc balance in grey scale imaging arise at least in part from the reduction in number of address steps compared with the number of grey scale levels. One way of deriving the grey scale value or combinations of grey scale values for use in operation of the multiple or weighted bit plane scheme, that is, replacing the input grey scale value derived from the intended image itself, is by means of a look-up table.

The weighted bitplane method as operated above does require that relaxation of the liquid crystal pixels is negligible over the duration of the longest bitplane, and this is not always possible. In such a case, the bitplanes can be refreshed during the bitplane period(s), but at the expense of dc balance. Nevertheless there are advantages in the ease of obtaining an accurately simulated grey scale.

Basically, a refresh step comprises repeating the application of the same voltage as was applied at the start of the bitplane so as to restore the switched state of the pixel. It may even be that the nth power binary weighted bitplane needs to be refreshed (2^n-1) times subsequent to the first writing so that a 2^n greyscale will involve 2^n frame writes of binary images when the refresh writing stages are included.

In the refresh scheme, bitplanes are read out more than once, depending on the duration thereof. Thus it is not possible to discard the bitplane until it has undergone its final reading. Furthermore, if each bitplane is repeatedly read for the requisite number of times before proceeding to the next bitframe, it is necessary to store the starting address of the two bitplanes.

For example, taking a simple case of three bitplanes A, B and C, of relative durations 4t, 2t and t respectively, it would be possible to read these out in the order AAAABBC. However, this necessitates storing the start addresses of each of the bitplanes, apart from frame C which is read only once, in order that the correct place for the refresh readout may be reached.

In addition, and perhaps more importantly, there are cases where it is necessary to rewrite the entire grey scale image before proceeding to a new image, where display times are long or relaxation is fast for example. In such a case it is necessary not only to store the start address of the bitplane next to be used, but also the start address of

5   the first bit plane of the entire sequence, until that image information is no longer required.

An improved method of readout in such cases makes it possible to avoid the storage of a plurality of start addresses. At the high speeds involved in reading out the

10   images when using the spatial light modulator of the preferred embodiment, this apparently minor step can be computationally significant and advantageous.

Essentially, the bitframes are stored as binary strings in sequential locations in a memory, in decreasing order of intended duration (weighting), a predetermined

15   number of read passes are made from the set of stored bitframes equal to the number of weighted bitframes, each pass commencing with the highest order bitframe and continuing along the stored bitframes in sequence, the lengths of the sequences being selected and varied such that at the end of the predetermined number of read passes each bit frame has been read out a plurality of times proportional to or equal to its

20   duration (weighting).

Thus according to this scheme, the triple bitframe image exemplified above will be read out with read passes ABC (once), AB (once), and A (twice), which when combined can give an overall order, for example, of ABCABAA, or ABCAAAB or

25   ABAAABC as desired. Only the start address needs to be stored since each read pass commences at the same place, and continues to an address determined by counters.

While some of the grey scale and refresh schemes above automatically provide dc balance, a further option for schemes which do not do this is to allow dc imbalance to

30   accumulate, for example while writing images and then allowing them to relax, calculating the imbalance (e.g. in an accompanying computer simulation), and then

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applying local dc voltages to the pixels of a magnitude and duration such as to provide zero average dc.

It should be understood that there have been references above to a liquid crystal cell incorporating an addressable array, the methods of the invention may be used in relation to array imaging device. Where the imaging device is a liquid crystal device, prolongation of the binary images used to synthesise the grey scale image may be achieved in known manner by the application of an ac field between successive binary images.

Furthermore, although the term "grey scale" is used herein, it should be made clear that the term is used in relation to any colour, including white. In addition, although the methods, arrays, backplanes, circuitry etc. of the invention are described in relation to a single colour (monochrome images), including white, it is envisaged that variable colour images or displays etc. will be produced in manners known per se, such as by spatially subdividing a single array into different colour pixels, superimposing displays from differently coloured monochrome arrays for example by projection, or temporal multiplexing, for example sequential projection of red green and blue images.

CLAIMS

1.   A method of grey scale imaging using a weighted bit plane technique, in which an n-digit binary number represents the intended grey level of each pixel location in an array of binary pixels, wherein at least one said binary number has an unequal number of 1s and 0s, said method comprising the step of altering the number to a closely adjacent value such as to reduce the inequality of 1s and 0s.

2.   A method of writing and displaying a grey scale image using a weighted bit plane technique, in which an n-digit binary number represents the intended grey level of each pixel location in an array of binary pixels, wherein at least one said binary number has an unequal number of 1s and 0s, in which a plurality of grey scale images each approximating said grey scale image are written in succession, said method comprising the step of altering the number to closely adjacent values in at least one of said plurality of images such as to reduce the inequality of 1s and 0s.

3.   A method according to claim 2 wherein said values of said number over said plurality of images provide an average grey scale level equal to the intended grey scale level.

3.   A method according to any preceding claim wherein said inequality of 1s and 0s is reduced to zero (equality).

4.   A method according to any preceding claim wherein said number is altered according to data in a look-up table.

5.   A method of signal processing for greyscale imaging in which weighted bitplanes corresponding to a greyscale image are stored as binary strings in sequential locations in a memory, in decreasing order of intended duration (weighting), a number of read passes equal to the number of weighted bitplanes are made from the set of stored bitplanes, each pass commencing with the highest order bitplanes and

continuing along the stored bitplanes in sequence, the lengths of the sequences being varied and selected such that at the end of the said number of read passes each bit plane has been read out a plurality of times proportional to or equal to its duration (weighting).

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6.   A method according to claim 6 or claim 7 wherein the said number of read passes is repeated.

7.   A method according to claim 6 when used to address a spatial light modulator
10   in the form of a liquid crystal display.

8.   A method according to claim 7, wherein a small ac potential difference is applied to pixels of the array in periods when images are not being written.

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16/12/09

Harrison   Goddard   Foote.